Internal Damage of Wheat Analyzed by Radiographical Examination

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DURING recent years criticism and concern have increased from grain traders and foreign buyers regarding quality of U.S. wheat, corn, soybeans and other grains and seeds. Apparently the United States is suffering significant economic loss through loss of quality or quantity in handling, storing, and transporting grains. Much poor quality is attributed to unsound kernels (broken and cracked).

Most investigations on physical damage of grains and seeds have been concerned with external damage. Some studies have been made with rice to investigate internal damage; less work has been done on internal damage of wheat. No evaluations have been made of actual amount of internal wheat damage in the field, relating to different varieties, methods of harvesting, locations, and years in which crops were grown.

The purposes of this investigation were to determine sources and amount of internal damage of wheat immediately before and after mechanical harvesting, and to provide information for corrective measures needed to minimize physical damage that may occur in handling operations and storage.

Examining cereal grains by X-ray techniques was first demonstrated by Milner et al. (9)* for checking insect infestation in wheat and other grains. These techniques have been used routinely for detecting and measuring internal infestation of grains for some time. Radiographical techniques have also been applied for detecting and measuring other physical irregularities in grains (5, 7, 10).

In studying physical properties of weathered wheat, Milner and Shellenberger (10) found internal fissures in weathered wheat using X-ray techniques. In their studies changes in physical properties, such as density, hardness and energy requirement for grinding, due to weathering, wetting and drying, were discussed in terms of radiographical evidence of internal fissures.

Studies of water penetration and internal cracking in tempered wheat grains were carried out by X-ray techniques (5). Hogan and co-workers (7) have used X-ray techniques for the rapid examination of rough rice for cracks, checks, insect damage and immature seed. The structure of rice kernels, as revealed by radiograph, was related to yields of head rice, color, stability to oxidation and nutritive value.

Kunze and Hall (6) and Stermer (11) investigated the relationship between environmental factors and physical conditions of grain causing fissuring of the rice grain. The effect of artificial drying on stress-cracked development in shelled corn and on breakage of shelled corn was studied by Foster and Thompson (3, 4). They evaluated stress-cracks in corn by a simple candling process.

MATERIALS AND METHODS

Three-phase experiments for investigating internal damage of wheat were conducted with Kansas HRW wheat over a two-year period (1966 and 1967). The internal damage of wheat was examined radiographically by a GE X-ray Grain Inspection Unit, rated at 25 KV peak and 5 milliamperes. Exposures were made on Kodak type M industrial X-ray film.

The first phase of the experiment studied the varietal effect on internal damage. Six varieties of HRW wheat (1966 crop)—CI 13284, Ottawa, Ponca, Scout, Triumph, and Wichita—from the KSU agronomy farm test plot were harvested by hand. Three replications were taken for each variety. Moisture content of the samples ranged from 9.0 to 10.5 percent. A Boerner sampler divided a sample into small portions from which a random sample of 100 kernels was taken to provide radiographs. In examining radiographs for the internal damage, wheat kernels were classified into two categories—single cracked and multiple cracked.

The experiment's second phase studied effects of variety, location, method of harvesting, and interactions on internal damage. Hand and combine harvest samples of four varieties of HRW wheat (1967 crop) -- Ottawa, Scout, Parker, and Wichita – were taken at each of three locations, KSU agronomy farm test plot, Newton and Hays Experiment Stations.

Both hand and combine harvesting for the corresponding varieties of wheat were done at the same time and at the same location in the field. Two replications were taken for each treatment combination. The moisture content range of samples ranged from 12.0 to 16.3 percent. The external damage and test weight of combine samples were evaluated. The sample for each treatment combination was examined radiographically for the number of single cracked kernels and of multiple cracked kernels.

In the third phase of the experiment, the year was an additional factor. Hand and combine samples of two varieties of HRW wheat, Ottawa and Scout, (1966 and 1967 crops) were sampled at each of two locations, KSU agronomy farm and J. Johns farm. Also, two replications were taken for each treatment combination. The moisture content of samples ranged from 9.2 to 11.5 percent. The sample for each treatment combination was examined radiographically as in other phases of the experiments.

RESULTS

Results of the internal damage of wheat kernels evaluated radiographically are shown in Table 1. Results are from the first phase of the experiment (varietal effect on the internal damage of six varieties of HRW wheat). Wheat from the 1966 crop was hand-sampled at the KSU agronomy farm test plot. The range of total damage observed was from 0.7 percent (Ponca) to 16 percent (Triumph).

TABLE 1. PERCENT INTERNAL DAMAGE OF HAND THRESHED HRW WHEAT (1966 crops)*

Location	Variety	Single cracked	Multiple cracked	Total cracked
		Percent	Percent	Percent
KSU test plot	CI 13285	7.3	0.3	7.6
	Ottawa	4.7	5.0	9.7
	Ponca	0.7	0	0.7
	Scout	1.0	0	1.0
	Triumph	15.7	0.3	16.0
	Wichita	3.0	0	3.0

* Average values of three replications.

Data for single cracked, multiple cracked, and total damaged kernels were analyzed separately by the randomized block design. Analysis of vari-

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* Numbers in parentheses refer to the appended references.

TABLE 2. PERCENT INTERNAL DAMAGE OF 1967 WHEAT* (TEST PLOTS)

Variety	Location	Method	Single	Multiple	Total
			Percent	Percent	Percent
Ottawa	KSU	Hand	41.0	52.0	93.0
		Combine	39.5	55.0	94.5
	Newton	Hand	14.0	82.0	96.0
		Combine	12.0	87.0	99.0
	Hays	Hand	5.5	94.0	99.5
		Combine	3.5	96.5	100
Scout	KSU	Hand	33.0	57.0	90.0
		Combine	26.0	66.0	92.0
	Newton	Hand	9.5	87.5	97.0
		Combine	4.0	95.0	99.0
	Hays	Hand	4.5	93.5	98.0
		Combine	3.0	96.0	99.0
Parker	KSU	Hand	27.5	66.0	93.5
		Combine	20.0	77.0	97.0
	Newton	Hand	10.5	88.0	98.5
		Combine	9.0	90.5	99.5
	Hays	Hand	8.5	90.5	99.0
		Combine	4.0	96.0	100
Wichita	KSU	Hand	23.0	71.0	94.0
		Combine	14.5	84.0	98.5
	Newton	Hand	11.0	86.0	97.0
		Combine	13.0	87.0	100
	Hays	Hand	1.0	99.0	100
		Combine	0	100	100

* Average values of two replications.

ance showed a significant varietal effect on internal damage for all three cases at $\alpha = 5$ percent, implying the varietal difference contributes to the difference in internal damage of wheat in the field. In this investigation, maturity dates of varieties could not be controlled. Some of this difference might be caused by the difference in the period of weathering.

For the second phase of the experiment, four varieties (Ottawa, Scout, Parker, Wichita), three locations (KSU test plots, Newton, and Hays Experiment Stations), and two harvesting methods (hand and combine) were studied. The 1967 crops were used to investigate the effects of these three factors and their interactions on the internal damage, making 24 treatment combinations for each replication.

The average values of two replications for single cracked, multiple cracked, and total damaged kernels examined radiographically are shown in Table 2. The ranges of percent single cracked, multiple cracked, and total damage for hand-threshed samples were respectively, from 1.0 to 41 percent; 52 to 99 percent; 90 to 100 percent. The ranges of percent damages for combine samples were from 0 to 39.5 percent for single cracked damage; 55 to 100 percent for multiple cracked damage; and 92 to 100 percent for total damage.

Data of single cracked, multiple cracked, and total damage were analyzed separately by 4x3x2 factorial design in randomized blocks to study the effects of main factors – variety, location, method – and of their interactions on internal damage. The analyses showed no difference on internal damage between replications, indicating that internal damage at each treatment combination did not depend on replications. Sampling appeared to be reliable.

Analyses showed a highly significant effect of treatment ($\alpha = 1\%$). Total treatment effect was broken into three main factors and their interactions (the first and the second order) in order to analyze each effect on internal damage. The main factors – variety, location, and method – and the first order interaction, variety x location, had highly significant effects on the single cracked and multiple cracked kernel damage; however, total damage of kernels was influenced only by location and method of harvesting.

The third phase of the experiment was designed to study the effect of the year on the internal damage. Two varieties of HRW wheat from 1966 and 1967 crops at each of two locations were sampled by combine and hand at the same time. There were 16 treatment combinations for each replication. Average values of two replications for single cracked, multiple cracked, and total damaged kernels are shown in Table 3.

Data obtained by radiographs for three categories of damage were analyzed separately by 2^4 factorial design in randomized blocks. As in previous analyses, no difference appeared on internal damage between replications of experiments, but highly significant treatment effect was observed. Individual analysis of each treatment combination indicated that the difference in each of main factors – method of harvesting, location, variety, and year – highly influenced the internal damage of wheat. Among interactions between main factors, the first order interactions, location x variety, location x year, variety x year; and the second order interaction, location x year x variety had to give significant effects on internal damage.

Discussion

This investigation was intended to examine general aspect factors of internal damage of wheat – such as year, location, method of harvesting, and variety – rather than fundamental aspect factors that might influence the internal damage. The year factor was considered a variable in which moisture adsorption, desorption or absorption, and drying characteristics of wheat would differ due to different weathering.

The location factor was assumed to be a variable in which the condition of soil, pre-harvesting treatment, and climate would be different. There are many hidden variables that cannot be controlled well in the factors considered in this investigation. However, these simplications might be sufficient to examine the general features of phenomenon. Many cracks in wheat kernels were already formed in the field before external forces from the combine at harvest were applied. The type of internal damage found in the hand-threshed 1966 crop samples were mainly single crack damage. In contrast, many multiple cracked kernels were found in 1967 crop samples. Considerable increases were observed on internal damage in hand-threshed 1967 wheat samples over those of 1966. Some samples examined were damaged 100 percent internally. The year 1966 was a normal harvesting period, but abnormal weather occurred in 1967 after crops matured. Harvest was delayed from one to two months in some Kansas locations. Severe internal damage of 1967 crops were attributed mainly to wet and dry weather variation which took place in the field after crops had matured.

Studies showed a combine tended to decrease the number of single cracked kernels and increase the multiple cracked kernels. Kernels already damaged in the field possess less resistance to external forces than those not dam-

TABLE 3. PERCENT INTERNAL DAMAGE OF 1966 AND 1967 WHEAT (FIELD SAMPLES)

Variety	Location	Method	1966 crop*			1967 crop*		
			Single	Multiple	Total	Single	Multiple	Total
			Percent	Percent	Percent	Percent	Percent	Percent
Ottawa	KSU	Hand	17.0	13.0	30.0	16.5	66.5	83.0
		Combine	24.0	24.7	48.7	20.5	74.5	95.0
	JJ	Hand	1.0	0	1.0	30.0	20.5	50.5
		Combine	8.0	0	8.0	23.5	43.0	66.5
Scout	KSU	Hand	2.3	0.7	3.0	26.0	57.0	83.0
		Combine	10.3	3.0	13.3	25.5	65.5	91.0
	JJ	Hand	0	0	0	18.5	43.0	61.5
		Combine	3.3	1.3	4.6	26.0	44.0	70.5

* Average values of two replications.

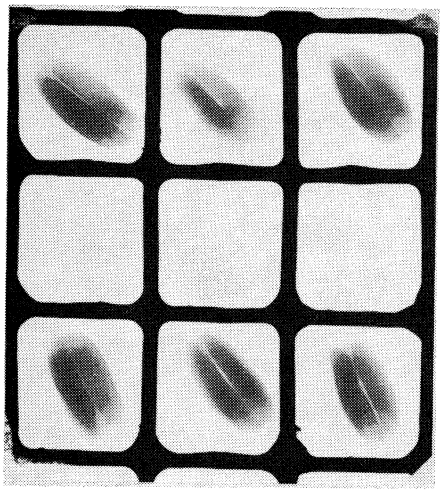

FIG. 1 The portion of the radiograph of hand threshed Ottawa wheat (1966 crop) at KSU farm (30 percent damage).

aged because they are weakly formed both chemically and physically. The reduction of single cracked kernels implies that the kernels become multiple cracked before additional single cracked damage is caused to kernels that have not been field damaged.

Internal damage of wheat was not only affected by each factor studied – year, location, method, and variety – but also by interactions of certain combinations of main factors (coupled sources), such as location x variety, year x variety, location x year, and even by the second order interaction, location x year x variety. Although significant effects of variety and method were observed, effects of year and location were much more pronounced than those of variety and method. Interactions found to give significant effects were coupled with either year or location. Formation of cracks in wheat was caused mainly by stresses arising from the moisture and temperature gradients within wheat kernels resulting from a climatical or environmental change.

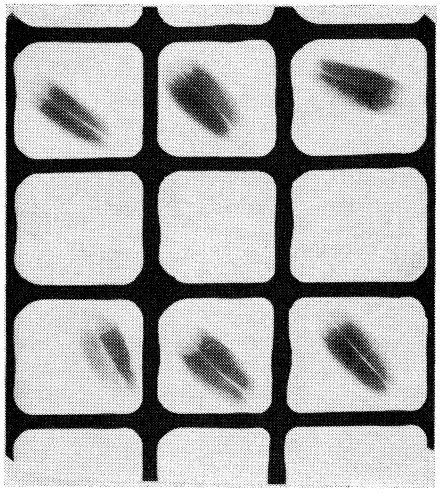

FIG. 2 The portion of the radiograph of combined Ottawa wheat (1966 crop) at KSU farm (49 percent damaged).

The X-ray examination of wheat in this investigation revealed that only radial cracks were formed in the endosperm part of the wheat kernel (direction normal to the crease). A definite relationship between the structural features of the endosperm part of the wheat kernel and the stresses arising from the moisture and temperature gradients caused such a formation of cracks in the kernel. It appears that the structural pattern in the endosperm of the wheat kernel is such that the gross lines of cleavages to be broken down to form cracks are oriented in the direction normal to the crease or to the surface of kernel.

Since the nature of forces associated at the lines of cleavages (commonly between or along the cell walls) is relatively weak, radial cracks were readily formed by stresses arising from the moisture and temperature gradients, breaking the intermolecular linkages between or along the cell walls. For example, four radiographs of Ottawa wheat, hand and combine samples of 1966 and 1967 crops (Figs. 1-4), show differences in the internal damage for each case.

Test weights of 1967 wheat were considerably lower than those of 1963 wheat, due to higher internal damage of 1967 crops. Cracks in wheat create pore spaces, reducing density and packing factor. Grains with many internal cracks are more susceptible to breakage in handling and increase in moisture movement during marketing and storage. Respiratory activity and tendency to deteriorate during storage and handling are greater for unsound grain than for sound grain (1).

Grains containing a high percentage of physically damaged kernels may be expected to harbor greater numbers of mold spores, insect eggs, and bacteria; and are much more likely to heat in storage than are sound grains of the same moisture content. In damaged grain the nutrients required for the growth of microflora at any given moisture content may be more readily available to microflora than they are in sound grains (8). Such unfavorable storage conditions would create further physical and chemical changes in grains.

Numerous practical inferences can be drawn from the present investigation. The increase in adsorptive capacity is expected in kernels with many cracks because of the increase of adsorptive sites resulting from cracks formed (2). Rates of adsorption of water vapor and adsorption of water increase in kernels with many cracks (10). This indicates that in the milling process less tempering and steeping time for grains with many cracks would be required than for grains with practically no cracks. Because the enhancement of moisture movement in grains often creates unfavorable storage conditions, quality of grain is lowered.

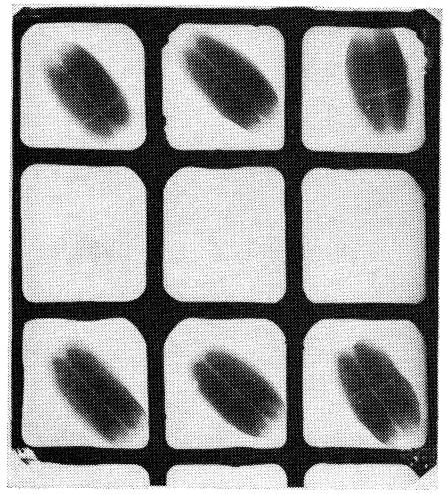

FIG. 3 The portion of the radiograph of hand threshed Ottawa wheat (1967 crop) at KSU farm (83 percent damage).

The decrease in hardness and energy requirement for grinding weather wheat (10) suggests that wheat samples with many cracks are easier to process during milling. Several millers observed this difference. On the other hand, grains with many internal cracks are more susceptible to breakage by handling operations. Thus, further investigations are needed on milling efficiency, quality change in storage, and susceptibility to breakage in handling operations of grains with many internal cracks. The study on the susceptibility to breakage of internally damaged wheat kernels will follow this report.

The radiographical examination of grain is useful in predicting quality of grain, in studying the structure of the cereal grain kernel, and in explaining the mechanism and rate of moisture movements in kernels for engineers who are concerned with harvesting, handling, storage, or processing grain.

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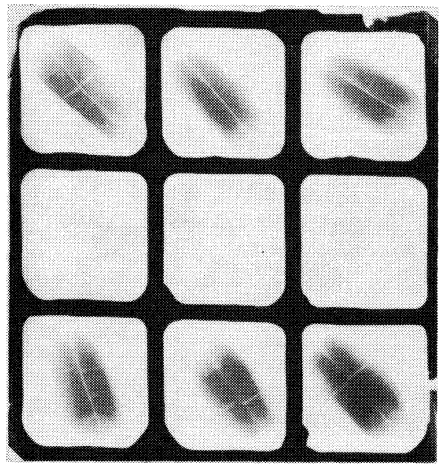

FIG. 4 The portion of the radiograph of combined Ottawa wheat (1967 crop) at KSU farm (95 percent damage).

INTERNAL DAMAGE OF WHEAT

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In addition, results of this investigation may help provide information needed for remedial measures to minimize physical damage of wheat.

References

1 Anderson, J. A. and Alcock, A. W. Storage of cereal grains and their products. Am. Assoc. Cereal Chem. St. Paul, Minnesota, 1954.

2 Chung, D. S. and Pfost, H. B. Adsorption and desorption of water vapor by cereal grains and their products, part III: a hypothesis for explaining the hysteresis effect. **Transactions of the ASAE** 10:(4)556-557, 1967.

3 Foster, G. H. and Thompson, R. A. Stress cracks in artificially dried corn. USDA, AMS-434, 1961.

4 Foster, G. H. and Thompson, R. A. Stress cracks and breakage in artificially dried corn. USDA, AMS-631, 1963.

5 Grosh, G. M. and Milner, M. Water penetration and internal cracking in tempered wheat grains. Cer. Chem. 36:260-273, 1959.

6 Kunze, O. R. and Hall, C. W. Relative humidity changes that cause brown rice to crack. **Transactions of the ASAE** 8:(3)396-399, 1965.

7 Hogan, J. T., Larkin, R. A. and MacMasters, M. M. X-ray and photomicrographic examination of rice. J. of Agr. and Food Chem. 2:(24)1235-1239, 1954.

8 Milner, M. and Geddes, W. F. Grain storage studies. iii, The relation between moisture content, mold growth, and respiration of soybeans. Cer. Chem. 23:225-247, 1946.

9 Milner, M., Lee, M. R. and Katz, R. Application of x-ray technique to the detection of internal insect infestation of grain. J. Econ. Entomol. 43:933-935, 1950.

10 Milner, M. and Shellenberger, J. A. Physical properties of weathered wheat in relation to internal fissuring detected radiographically. Cer. Chem. 30:202-212, 1953.

11 Stermer, R. A. Environmental conditions and stress cracks in milled rice. Cer. Chem. 45:(4)365-373, 1968.